Chapter 4
Engineering and Construction Issues

4-1. General

Specialized engineering resources may be required for prefabricated methods of construction. Needs will vary during the many stages of development and must be anticipated in the budget and schedule. These construction methods require site-specific analysis of the main project site and possibly a similar analysis of a potential remote fabrication site. Testing, research, or additional design may be required to prove feasibility of designs. The design team must have thorough knowledge of concrete design principles, concrete materials, heavy marine construction practices, and environmental loading (particularly for the wave effects on float-in structures). Most of the existing design guidance is applicable to these methods of construction. Geotechnical guidance contained in EM 1110-1-1904 and EM 1110-1-1905 is still applicable. Hydraulic design guidance in EM 1110-2-1604 is applicable, as is general guidance in EM 1110-2-2602. Designers may find useful, but not complete, information in EM 1110-2-2104 and EM 1110-2-2906 for reinforced concrete and pile foundation design, respectively. Design criteria may have to be developed for tasks related to design of concrete shells since little guidance exists. Some construction tasks will vary from the traditional methods of construction mostly because of the need to work from floating plant. Much of the project will never be visually inspected which will require nontraditional methods of assurance that specifications have been met. Assurance of a quality product requires experienced and trained inspectors. This chapter will identify project features/tasks that are unique to prefabricated methods of construction. In general, these features/tasks are emphasized because they either need to be started early in the design or require atypical engineering resources.

4-2. Site-Specific Issues

a. Onsite issues.

(1) Work areas. Planning and selection of all necessary onsite project work areas is a very important consideration. Traditional construction of navigation projects generally is conducted by delivering relatively small components or raw materials to the site where they are assembled in situ. However, prefabricated methods of construction could involve the transporting, storing, handling, and maneuvering of large shells at the construction site. At the beginning of the Feasibility Study, planners, engineers, and key construction personnel should be included in the selection and evaluation of all onsite project work areas including laydown areas and supplemental work areas for construction of the project. It is essential that by the completion of the project Feasibility Study that the boundaries of the onsite project work areas be defined to the fullest extent possible. This will permit selection of necessary real estate (i.e., temporary or permanent) and allow real estate actions to proceed. Early resolution of these areas will also permit environmental/cultural resource/HTRW (Hazardous, Toxic, and Radioactive Waste) compliance studies to begin. Each area considered should be evaluated based on various key points including size, access, environmental characteristics, history of use, and potential for acquisition. Considerable space requirements may be needed for the larger components and vessels associated with prefabricated construction. Unique mooring requirements may be required for floating plant, floating shells, and storage of large lift-in shells delivered by waterborne transport. Floating plants may be more numerous or larger than traditionally used, therefore requiring special attention. Onsite storage of floating shells may be required. Dredging and other excavations that may disturb the environment should be evaluated. The addition, deletion, and/or adjustments in limits of onsite project work areas after the real estate actions and environmental/cultural/HTRW compliance studies have begun/finished will likely result in unwanted delays to the project schedule and cost escalation in the project budget may occur.

(2) Real estate issues. Real estate acquisitions for onsite project areas shall be conducted in accordance with ER 405-1-12. Although the real estate acquisition work may be based on a valid plan, a contractor acting within a performance specification may develop an acceptable plan that crosses approved real estate bounds. Additional real estate action may result in time delays, but the technical merit of the plan may justify the delays. The contract documents could consider such an occurrence.

(3) Delays to navigation during construction. The onsite construction of navigation structures could affect the performance of the navigation channel or existing lock(s) resulting in delays to the user. Lock closures of short duration yet frequent or long duration and infrequent have different economic impacts. Delays that cannot be avoided should be quantified for economic comparisons with other alternatives. The engineer should consult with Operations and the User on what types and/or timing of delays are less costly to the User. Scheduled lock outages can reduce economic impacts. For lock closures, scheduled outages are necessary for activities such as driving piling or excavating bedrock in the line of navigation. Subsurface investigations and pile driving tests that assist in developing production rates for foundation work would help quantify delays. This may supplement historical production rates that may not be fully applicable for in-the-wet and prefabricated methods of construction. Advice from experts on production rates and constructibility can be elicited for tasks that have little historical information (senior-level estimators from construction companies have been assembled to provide this type of information). Quantifying impacts to navigation involves determining the construction procedure and sequence, determining task durations and dependencies, and producing a construction schedule. This work serves as input to the economic analysis to determine the cost of the delays. During construction, temporary measures such as helper boats, temporary mooring areas, ready-to-serve policy, and Industry self-help can help reduce lost efficiency of the lock. The usefulness of these measures can be project- and site-dependent. These measures must be considered in the cost estimate and economic analysis. The contract documents should include all navigation conditions during which the contractor will not be able to work. Full closure of either locks or the river must be included as well as periods that the contractor can temporarily block navigation either for crew, material, or equipment movement. Liquidated damages or other consequences must be considered for which the contractor will be liable in the event of inexcusable delays.

(4) Studies and investigations.

(a) Environmental concerns and cultural resources. An overall Environmental Impact Statement (EIS) will be developed as part of the project Feasibility Study. The EIS will address the environmental concerns and impacts associated with the project configuration and onsite project work areas. Public health regulations and/or special environmental constraints will be identified within the EIS, as will issues regarding HTRW handling and disposal. The EIS will also identify necessary permit actions and mitigation requirements. It is important that the project configuration and onsite work areas be as well defined as possible so that the EIS be comprehensive in order to minimize the need for a Supplemental Environmental Impact Statement (SEIS) and/or Environmental Assessment (EA). Prefabricated construction methods won't have large cofferdams; therefore, the lesser footprint along with a shorter in situ construction period will reduce environmental disturbance. Realistically, the project features and onsite work areas will become refined as the design nears its completion. It is therefore important that environmental and cultural specialists responsible for preparation of the EIS and/or possible SEIS and EA be updated on the project's design, proposed construction operations, location and extent of project work areas, or other issues that could influence environmental and cultural concerns. These notifications are critical to project execution so that appropriate supplemental reports may be made and public notices issued in a timely manner with the least impact to the project schedule.

(b) Geotechnical. Typically, geotechnical investigations include a program of soil/rock sampling and testing to gather information to complete the designs for foundations and other related project features. Besides these traditional investigations, unique testing may be in order since prefabricated structures have foundation systems that are built in-the-wet. Systems of piles and drilled shafts are typical foundations used for innovative solutions. Full-scale field tests may be in order to investigate the soil/rock/structure interaction and the lateral and axial capacity of the piles. The full-scale test piles should be built in-the-wet to accurately simulate actual field conditions. The cost of full-scale field testing is justified if the results will help to optimize the final foundation system design, thus saving money during the actual construction. The full-scale field tests will also provide valuable information related to the methods and procedures to be used to build the foundations in-the-wet. Other types of field investigations may include: soundings and underwater probing; evaluation of the susceptibility of foundation materials to scour; drainage and seepage analyses; and investigations of stone and aggregate sources. The designers should consider performing these unique tests along with the typical exploratory investigations as early as possible in the design schedule, such as during the Feasibility Study. Test results may then be incorporated into the final design, thus eliminating the need to perform these investigations and tests during the construction as prerequisite work.

(c) Hydrology and hydraulics. Studies must be performed to ascertain the critical hydraulic characteristics that may affect the project design and construction. Velocities and water levels will likely be the most typical hydraulic concerns affecting the project. There will be a recurring pattern of river stages or tides that are typical to the area where the project is built. These patterns must be thoroughly understood to determine their effect on the setting of prefabricated subassemblies. These water-level patterns will impose forces on the prefabricated subassemblies that affect loading cases. In general, water velocities will create forces on the subassemblies and final structures that will need to be considered in the design. In colder regions, ice flow and loads imposed by ice will create another condition to consider. River and tidal conditions will also influence the setting procedure and sequence. The effect of river velocities on positioning tolerances must be considered. Studies may also include investigations of Federal flood control projects and hydroelectric projects that could be coordinated to control flow in the river. Hydrologic and hydraulic conditions can influence the duration of the construction contract and may dictate the best time to award the contract. Seasons having typically high flows may not be suitable for placing precast shells or other facets of in-the-wet construction. All available hydrologic and hydraulic information must be carefully reviewed to determine conditions that might constrain construction activities. Where hydrologic information is insufficient, it must be completed to the necessary level of detail to thoroughly understand the hydraulic characteristics of the environment in which the project will be built. Sediment transport and deposition may also need investigation where this condition could affect dredging operations, excavations, and foundations. Physical constraints of the watercourse, such as the navigable width of river and swellhead that may affect floating plant or project features, must be considered. The Project Engineer must schedule any unique tests required to understand these conditions as early as possible in the design schedule, such as during the Feasibility Study, to assure that the necessary information is available when the final designs are formalized.

b. Offsite issues.

(1) Work areas. Offsite work areas may include a number of sites where various components of the project will be built or partially built and then delivered for assembly or further prefabrication. Large structural features such as miter gates, flow control gates, valves, and other miscellaneous structural fabrications will likely be built at existing fabrication yards and transported to the site. Similarly, large prefabricated subassemblies will be fabricated and transported, but will require a prefabrication site that may need development and/or adaptation to meet the project requirements. This prefabrication site may be an existing facility that is already suitable with little or no adaptation, or may be one that requires complete development to accommodate the work. Regardless, the site will need to be connected to the project site by navigable waters. There are two basic choices for the selection of the prefabrication site:

- Government-Furnished Prefabrication Site: The Government must conduct all necessary planning and engineering to fully evaluate potential sites, whether they are existing or require development, and select a site for the project. Factors such as size of the site, proximity to the project site, subsurface conditions, flooding and land use history, and navigation impacts must be considered. The Government must complete all NEPA (environmental/cultural/historical and HTRW) compliance investigations, and also conduct all necessary real estate actions for the site offered. The real estate action could involve acquisition of permanent and/or temporary land interest. The benefit of a Government-furnished prefabrication site is that all bidders will be developing their proposals based on a common prefabrication site. This will eliminate the need for contractors to seek out sites and secure the necessary real estate agreements, as well as eliminate the need for the contractor to expend time and costs for environmental permitting. The drawback is that the level of effort dedicated to the selection and acquisition of a prefabrication site will require significant time and must be funded appropriately. In addition, the contractors will not be given the flexibility of using lands or sites that they already may own or have land interest in. This could result in a higher total cost for the prefabrication site.

- Contractor-Furnished Prefabrication Site: All work that the Government would perform in selecting a site falls to the contractor during the proposal phase. The benefit of this is that the contractors are given flexibility of using lands that they may already have land interest in, thus, resulting in some cost savings. The drawback is that the contractor will be forced to perform all the required NEPA (environmental, cultural, and historical) compliance investigations on their own, and secure all the necessary environmental permitting for the project. There will not be suitable time during the proposal phase to complete all of this work. Therefore, there will be some uncertainty, or risk, associated with a contractor-furnished site. Upfront contract time could be squandered to complete the necessary NEPA compliance and permitting. There is also the risk that the contractor’s site will not be usable as proposed.

NOTE: Prefabricated subassemblies have also been successfully constructed on large floating barges (Montezuma Slough) (see Appendix C). This could be a consideration if the Government or contractors are not able to find a suitable site proximate to the project site.

(2) Real estate issues. The process of acquiring any Government-furnished offsite project work areas is similar to those actions required for onsite project work areas.

(3) Impacts to navigation during construction. Construction of the prefabricated elements at the offsite project work area should not create adverse impacts to navigation. However, the impacts with launching and transporting these elements should be given consideration when planning the project schedule.

(4) Studies and investigations.

(a) Environmental concerns and cultural resources. The overall Environmental Impact Statement (EIS) that is developed as part of the project Feasibility Study should address the environmental, cultural, historical, and HTRW characteristics and impacts associated with any Government-furnished offsite project work areas. However, if the offsite work areas involve contractor-furnished sites, a Supplement Environmental Impact Statement may be in order.

(b) Geotechnical. Investigations will be similar, although not as extensive, to those conducted for onsite project work areas. As before, the Government should consider performing as much upfront exploratory investigations and field tests as permitted by the design budget in order to eliminate the need of performing these investigations and tests during the contract as prerequisite work. Early investigations would be needed to discover if the soil at a potential prefabrication site is suitable for heavy construction.

(c) Hydrology and hydraulics. Hydrologic and hydraulic studies should be conducted for the offsite project work area, similar in nature to those performed for onsite work areas. Of particular concern will be the transportation constraints of the watercourse, such as the flows, navigable width, and available draft between the prefabrication site and the project site. These parameters should be investigated to at least a cursory level of detail leaving a detailed investigation to the contractor.

4-3. Engineering Issues

a. Conceptual designs. The development of conceptual designs begins with researching available information on all types of innovative construction techniques to increase the engineer's knowledge of what can be done. Thorough knowledge can provide more solutions to particular problem areas of a project. Prefabricated elements are a particular set of solutions. Some projects have used precast concrete shells as stay-in-place pile driving templates and stay-in-place concrete forms. The use of shells and underwater concrete eliminates the need for large cofferdams. The connection of the shell to the foundation may often be done with concrete placed underwater. The shell can contain structural reinforcing steel requiring that load is transferred from the fill to the shell. Monoliths for navigation projects are generally large and may lend themselves to being assembled in pieces to reduce handling loads. Joints will occur between adjacent subassemblies and are generally areas in which to concentrate design efforts. Construction procedures and sequences are important aspects of conceptual designs. They require the engineer to think through the feasibility of the concept/project. Construction procedures and sequences along with other design assumptions could be included in the plans and specifications to convey the intent of the designer and to show the contractor that there is at least one feasible way to construct the project. Conceptual designs should be analyzed for equipment requirements to determine their dependency on certain types of equipment. Dependency on special equipment may limit the number of contractors and/or raise the bids for the project. In general, limitations on size, transportation, productivity, etc., can be restricted by available equipment. Large-capacity crane barges, stiffleg derrick cranes, or possibly ringer cranes on barges could be required. Designing within the limits of available cranes should yield the most competitive bids. Two cranes could be used to hoist shells. Along with crane barges, a significant amount of other floating plant may be required. Floating plant may be used to transport precast shells, shuttle materials and manpower, support cranes, support concrete conveyors, pumps, or tremie pipes, stage diver inspections/activities, drive piles, etc. Marine facilities have to be established to moor, repair, and modify vessels, load materials, transport workers, etc. Existing plant can be modified to suit successive phases of construction or special equipment may have to be built for the project. The benefit of special equipment becoming Government property should be investigated. Catamaran barges for placing shells have been made from flat deck barges paired together with strongbacks. The strongbacks have hoisting capabilities to raise and lower shells. Lateral location of the catamaran is controlled by cable and winching of the barges in response to survey information. Large floating plants are less susceptible to movement from wind, currents, and waves. Currently, the research and development program is tasked with developing a detailed reference for equipment requirements. In summary, the development of alternative conceptual designs should include factors such as first cost, life-cycle cost, operation and maintenance cost, cost of delays to navigation during construction, constructibility, and equipment needs and availability.

b. Concrete materials and concrete investigations. A significant benefit of prefabricated construction will be the increased structural durability from using specially formulated concrete and grout mixtures. Concrete used for the fabrication of structures may include precast concrete, conventional cast-in-place concrete, and high performance concrete. Special grout mixtures may also be required. Standard weight and lightweight concrete may be required for various parts of the structures to enhance flotation and handling. Concrete and grout mixtures will most likely be placed both in-the-dry and underwater. Concrete mixes placed underwater by tremie methods must flow freely, be self-consolidating, and may need to exhibit a resistance to washout. Most concrete mixtures will be composed of special formulations of cement, aggregate, pozzolans, and specialized admixtures. This will require that most proposed concrete design mixtures be trial batched and tested to verify that the required design strengths, as well as the physical characteristic, can be achieved. The thermal characteristics for concrete mixtures for precast concrete and mass concrete used to fill shell structures will also need to be studied. This information will be used to support a Non-Incremental Structural Analysis (NISA) to study the structure's response to effects of concrete thermal activity. This could lead to design decisions related to reinforcing and possible prestressing/post-tensioning for strength and/or crack control. Concrete field demonstrations may also be in order depending on the complexity of the proposed concrete placements. The project schedule and budget must have sufficient time and funds dedicated to permit the completion of these necessary concrete design studies. Increased structural durability will be achieved through an enhanced program of quality control for all phases of concrete batching, mixing, and placement. The design should be investigated to determine where uncertain areas might be and how anticipated deficiencies could be repaired. Generally, the precasting of concrete results in a higher quality finished product. Adding to quality can be casting positions, match casting, preassembly to ensure fit, and possible indoor construction (clean rebar and controlled environment for placing and curing). A precast yard would have to be Precast Institute (PCI) certified. For a new precast facility, this certification could be time consuming. A contractor may opt to have a certified plant/precaster do the work or at least fabricate smaller sections that can be connected later. At the construction site, units/panels can be connected or most would eventually require filling with concrete/grout. The voids to be filled cannot restrict the flow of the concrete. Means to ensure the quality and thoroughness of concrete placement should be specified.

c. Hydraulic investigations. This paragraph supplements paragraphs 4-2*a*(4)(c) and 4-2*b*(4)(c). Hydraulic investigations may be necessary to study boundary conditions (i.e. maximum flows) that dictate when the prefabricated structural elements can be handled and set. Investigations may help determine key loading conditions that are needed to complete designs, and they could provide important insight to the conditions for which it would be safe for divers and other construction personnel to work. Generally, physical models and numerical models will be used to acquire this information. The scale of physical models must be properly selected to assure that the appropriate parameters are measurable. Numerical models should be used to augment and/or supplement the information collected from physical models. It is important that scaled physical models of the project work site be developed. These models can be useful to understand key factors such as confinement of the river and/or navigable passage, setting schemes and sequences for the prefabricated subassemblies, tracking paths for transport and positioning of the prefabricated subassemblies, and to study the forces on elements as they are being placed. Other information gained from these models can be provided to the contractor for design of temporary structures such as mooring systems.

d. Cost engineering. Generally, the percentage of engineering costs relative to construction costs will be higher for prefabricated navigation projects. This must be determined and accepted in early stages and programmed in the project management plan. Costs associated with specialized expertise, special testing, field mock-ups, models, and quality assurance during construction will generally exceed routine requirements. For the actual government estimate, there will not be a comprehensive database to reference. Specialized expertise and additional time may be required to develop the cost estimate. Uncertainties must be reduced to an acceptable level. Contingency costs should not be used to cover uncertainty. Use of the construction sequence will facilitate identifying tasks. Costs for training designers and inspectors, and special equipment, special monitoring and mobilization costs may be higher than those for traditional construction and must be considered in the project-funding plan. As projects utilize these methods, the database will be expanded.

4-4. Design Criteria

a. Structural design criteria. As of this writing, most existing criteria have been developed for traditional, in-the-dry methods of construction. Existing criteria may not always be applicable for these construction methods, but should be used when possible. Existing criteria and guidance that prescribe general design requirements, concrete finishes, stability requirements, life-cycle cost analysis, etc. should be usable. Prefabricated methods of construction can result in projects looking the same as traditionally constructed projects and be capable of complying with existing criteria. Where criteria do not exist, resources should be allocated for development. The needs for design criteria should be identified after the recommended conceptual design is known. In general, there is little guidance for tasks related to the design of the shell itself. Criteria for precast, prestressed/post-tensioned concrete are critical for these construction methods and are currently being developed. Crack control criteria are important for appearance, integrity of buoyancy chambers, and protection of reinforcing steel. Concurrent with the development of this engineer circular, a Research and Design project is developing design tools and construction methods for constructing navigation projects. Other sources for criteria can be found in design documents for projects using prefabrication methods, such as, American Petroleum Institute publications for offshore platforms, ISO 13819-1, ACI 357.2R State of the Art Report on Barge-like Concrete Structures, ACI 357R Guide for the Design and Construction of Fixed Offshore Concrete Structures, AASHTO standards, Precast Concrete Institute publications, etc.

b. Loads and load combinations. Prefabricated methods of construction require careful attention to the many different loads and load combinations on the shell as it is being built up and the developing structural system's strength to resist the loads. Loads will change during the various stages of shell fabrication, transportation and handling, installation, and concreting of the units. Unlike traditional concrete construction for which the loads and load combinations from concrete placement and the design of shoring are generally the responsibilities of the contractor, the design engineer should consider these aspects as part of the shell design. The principles of naval architecture will be required to determine the forces on floating shells resulting from wave action. The buoyancy forces keeping the unit afloat are transient due to waves. This is referred to as sagging and hogging. The design wave, which is characterized by its return period, wave length, frequency, and height, will often control the design of floating units and the locale where it is constructed. For example, wave design assumptions on inland waterways would not result in a unit that is strong enough to transit the open seas. To reduce draft during transportation, the shell may require supplemental buoyancy tanks that will impart their own loads to the shell. Designers should consider that some chambers in floating units might accidentally flood. During the installation of shells, forces from ballasting the unit to its position should be considered along with the forces from landing shells onto their landing pads or foundation. Since large units can be constructed in segments, the design should consider loading conditions on segment connection details. Thermal loads resulting from the heat of hydration from concrete fill should be considered because these forces can crack the shell.

4-5. Structural Systems

a. General. Traditional structural systems do not necessarily change with the use of prefabricated methods. Gravity and U-frame monoliths will remain as the likely end product, but prefabricated methods are used for their construction. Also, thin-walled monoliths have been considered as alternatives and are constructable with prefabricated methods. Large monoliths can be built up using smaller precast concrete shells or panels. Load transfer between shells can occur through the shells or fill concrete. Floating approach walls offer another system composed of a floating superstructure connected to anchor points at its ends and possibly at intermediate points. Further discussion is divided into superstructures and substructures. Precast concrete shells are presented for describing structural systems.

b. Superstructures. Structural systems for precast shells will consist of typical structural elements such as beams, slabs, brackets, panels, shear walls, etc. These elements are connected together to form a shell that is floated or lifted onto its foundation. Connections between units/elements should be designed for ease of construction, strength, and durability. Prestressing, post-tensioning, and conventional reinforcement will be used in some combination to make connections along with strengthening and controlling cracks in concrete. Shells must be designed to minimize weight for handling by cranes or to reduce the draft for floating shells. Localized strengthening of the shell with steel shapes or thickened concrete at attachments for mooring/handling lines or to act as a hull (for floating units) may be required. The structural system could be designed to use only sand fill to resist impact, uplift, or otherwise stabilize a monolith. Bond of concrete fill to the shell would be required if the shell cannot resist the applied loads. Surface preparation/cleanliness, material compatibility, material strength, joint details, dowel strength, and placement techniques influence the bond of fresh concrete to hardened concrete. Also, the shell should be configured to not impede the flow of fill concrete (usually tremie); therefore, consideration must be given to ancillary items/features, such as temporary supports, corners, and grout supply and vent tubes. These, or similar items, and items added by the contractor must be scrutinized. Using specified criteria, the construction inspector should inspect underwater forms just before they are submersed. Construction joints should be located in areas of low stress and may require special seal details if watertightness is required. Joints should generally be watertight to contain cement paste. Units may be constructed segmentally and post-tensioned together while afloat or on a slipway. The structural load-resisting system and the load on the system will probably change as the shell is built up. For example, the shell could serve as a cofferdam by pumping it out after it is sealed to its foundation using tremie concrete. The construction/fabrication sequence should be analyzed for such occurrences.

c. Substructures and foundations.

(1) Foundation materials and preparation. Prefabricated methods of construction require that the foundation excavation and other in situ preparation be done in-the-wet. Excavations are susceptible to scour, siltation, and slope stability problems. Soil foundation materials would be susceptible to scour from naturally occurring river velocities and/or induced high velocities created by constricted flow of water around shells. To help prevent scour, the natural material can be over-excavated and replaced with scour stones or bags filled with sand or stone. Stone provides other benefits in that it can be screeded to achieve a level surface for subsequent construction and if underwater concrete is to be placed against the foundation. The stone will not mix with the concrete as much as sand or other finer material. Rounded stones are more easily screeded than crushed stones. Underwater excavations may also be difficult to maintain due to migration of the riverbed. River hydraulics and bed-load characteristics would help identify scour and deposition potentials. For rock foundations, unsuitable rock can be excavated. Experience has shown that both production and tolerances can be met using large hydraulic excavators that can rip relatively weak bedrock and also excavate it. There are a limited number of these excavators because they are very expensive, but large jobs may justify the purchase of such equipment by the contractor. The foundation design would have to accommodate reasonable tolerances for excavation of rock underwater. Alternatively, drilled shafts can be used to reach through poor rock to layers of sound rock, minimize rock removal, and provide lateral strength.

(2) Pile and drilled shaft installation in-the-wet. Piles are typically installed in-the-wet for prefabricated methods of construction. Piles can be driven from floating plant using various hammers with fixed or swinging leads. Depending on the depth that a pile is to be driven will dictate the need for use of followers during pile driving. Conventional impact and vibratory hammers are utilized above water. Recent introduction to the U. S. of underwater impact hammers has provided unique capability to the installation of pile foundations above and below the water surface. The design of a pile foundation should take into consideration the tolerances that can be reasonably achievable between individual pile elements. Achieving tighter tolerances will be reflected in the cost for installation due to the preparation and quality control during pile driving. Site characteristics will certainly influence the driving of different types of piling. Soil densities that are very high will be less receptive to displacement piles whereas soils with low densities will benefit from the same types of piling. Site characterization is a must for any site where installation of a pile foundation is anticipated. Densities, size of particles, frictional capacities, end bearing capacities, and depth to rock or a firm strata are a few of the characteristics that are important in the design and installation of pile elements. Based on the subsurface conditions pile tips may be

terminated at varying elevations resulting in different elevations for the pile tops. Pile lengths should be set with close tolerance to avoid the necessity to cut piles to proper length underwater. Design concepts that feature shells and are designed to prevent bottom heave will allow piles to be cut off in-the-dry.

(3) Substructure to superstructure interface. Regardless of the type of foundation material or preparation, load transfer of a completed monolith to its foundation will be required. Generally, concrete would be placed in the shell and against the foundation structure to connect the two. Prior to placement, it would be verified that the unit is sealed against the foundation in order to contain the subsequent fill concrete and verify that the condition of the surfaces and formwork meet specifications. Assumptions for resistance to sliding at a rock-to-concrete interface require careful attention. Bearing pressures may not be uniform due to unequal cleaning/preparation of the bedrock. Assumptions for design values of bearing on bedrock need to be made. For pile foundations, the piles are either predriven or are driven through the shell or through pile wells in the shell. Loads are transferred to the pile system through concrete fill or grouted connections. Tension piles can be developed into the concrete by welding beads on the pile that perform a function similar to deformations on rebar. This practice, used for offshore platforms, eliminates the interference to pile driving by devices such as tension transfer weldments.

d. Connections. Prefabricated elements are generally assembled into a final shell using various types of connections. Connections must be designed with careful attention to detail. Key design aspects of connections are the accounting for tolerances in the placement of adjoining pieces and the need to transfer loads across the joints. The transfer of loads through connections may be more critical than for conventional cast-in-place construction. The combination of axial, shear, moment, and torsion reactions at a connection need to be determined. Some connections will be made underwater or otherwise hidden from view. The connecting of critical joints in-the-wet should be minimized. The designer must anticipate the resulting quality of such a connection and provide reserve capacity and/or redundancy accordingly. There are methods to confirm the quality of a connection such as diver verification and/or acoustic sounding. Connections of the superstructure to pile foundations and to adjoining elements are of paramount significance. Large elements, such as immersed tubes and floating bridges, have been connected together with post–tensioned rods that are threaded through preformed holes in adjoining walls. Sealed voids between immersed tubes have been dewatered allowing external hydrostatic pressure to force the two tubes together. Rods are then tensioned to positively adjoin the two tubes. The long-term performance of connections may require an investigation into the fatigue and fracture characteristics of the connections. Also, joints may have to be watertight to ensure that the cement paste from contained concrete does not wash out. The durability of a project is dependent on details such as connections.

4-6. Construction Issues

a. Project construction schedule. A construction schedule should be developed for each project alternative during the Feasibility Study. The content should be consistent with the detail necessary for the decision process. When project schedule is an important consideration to the decision process, extra detail may be needed for the Feasibility level construction schedule. A more detailed project construction schedule, using a Network Analysis System (NAS) approach, must be completed later for the selected project alternative during the design phase. This schedule must be as thorough as practical and must assure that the correct tasks, durations, and dependencies associated with the proposed innovative techniques are addressed. The schedule should be formulated from input gathered from design team members in planning, engineering, construction, and operations, as well as A/E firms and/or expert consultants. The construction schedule should thoroughly and clearly identify activities at the onsite project work areas and offsite project work areas, such as critical construction periods, contingency plan schedules, lock closure periods, and periods of reduced lock efficiency, etc. The schedule must reflect periods of river conditions (i.e. river stages and velocities) during which work will be affected or will not be possible. Environmental factors such as fish migration and spawning periods must also be duly considered in the construction schedule. ER 1-1-11 provides policy on the use of the various schedule management methods.

b. Contractor Quality Control (CQC). There will be a need to have separate CQC staffs for projects involving offsite fabrication. One staff will be stationed at the project site while the second staff would be located at the prefabrication site. The use of the same CQC staff for both locations would only be recommended if the project site and prefabrication sites are reasonably close to each other. One CQC Manager should be able to supervise and manage both staffs, unless the project site and prefabrication site are far apart. Two CQC Managers may then be recommended. Qualifications and performance expectations of the CQC team must be identified and clearly specified in the contract specifications. The contract specifications must also entitle the Government to review and approve all CQC personnel. Because of the uniqueness and complexity of prefabricated construction, the level of coordination must increase. Progress meetings and safety meetings will need to be conducted more frequently. Construction mock-ups that simulate the actual construction methods and sequence may be required where the task is highly complex and critical in nature. Nontypical inspections such as commissioning trials (float-in structures) and other inspections to document responsibility in the event that the structure fails or is damaged during handling, transport, or placement will most likely be needed. Specialized training for construction inspectors may be required. It may be necessary for the contractor to supply a third party trainer for his CQC staff.

c. Quality Assurance (QA). The Government will perform Quality Assurance of all Contractor Quality Control measures in accordance with ER 1180-1-6. There will be a need to have adequate Government QA staff for both the project site and prefabrication site. If the prefabrication site is some distance from the project site, two Government QA staffs may be needed. Much of the work involving prefabricated construction will require specialized construction knowledge to properly assure the adequacy of the contractor's work and CQC program. Government construction representatives will need to be specially trained. Some of this training may be provided through available sessions offered through the Huntsville Training Center, associations (i.e. ACI, PCI/PCA), or other accredited educational institutions. However, most training for innovative construction techniques is probably not available and will need to be developed. An accurate logging of "lessons learned" will facilitate training of Government inspectors for future projects. Another tool to inform Government construction representatives of key aspects of the critical project design and construction issues is through a formal "Engineering Considerations and Instructions to Field Personnel" report as explained in Appendix E, of ER 1110-1-12. Although in-house personnel will serve to staff the majority of the Government's QA program, specialized expert staff may be needed to supplement the in-house Government staff. Supplemental specialized staff may be procured through A/E service contracts or through direct hire of an expert consultant.

d. Adverse weather. The advantage of prefabricated construction is that significant portions of the structure can be built under controlled and protected conditions. For instance, precast concrete can be manufactured within temporary climate-controlled enclosures permitting protection of the precast elements along with ideal curing conditions. Another benefit of using prefabricated offsite construction is that the prefabrication site can be better protected from adverse weather and most river conditions compared to the exposure if the structure was built inside a cofferdam. The Project Team must thoroughly understand the adverse weather patterns associated with the project site and prefabrication site so that the project schedule allows for the expected adverse weather patterns at these sites. A well thought out schedule must account for or mitigate adverse weather effects on prone processes/activities.

e. Contractor submittals. Numerous unique submittals will be required from the contractor. Many of these submittals will require review by specialized experts. There is a possibility the contractor may submit alternative designs that must be thoroughly reviewed by qualified personnel to assure that the design intent is preserved. The designer must thoroughly review the work and compare it with the

Government-proposed construction sequence, created during the plans and specifications, to identify when a contingency plan is required. Contingency plans will be submitted for features of work that are critical or those that may be affected by adverse weather or other unforeseen occurrence that is out of the control of the contractor or Government. The designer may also establish performance-based specifications for such plans and include these in the contract tender documents, but the contractor will ultimately be made responsible for development of the plan.

b. Safety. These methods of construction require heightened safety awareness due to the need for heavy lifts with large equipment, confined spaces within the shell, high pressure lines for jacks, and the fact that the majority of the work would be performed over water. The construction procedures should be examined for safety of personnel and for protection of the environment. Contract documents should make the contractor aware of times for need of heightened safety awareness. The designer should consider safety throughout the design and develop safety-related instructions for the field. When divers are required, approved dive safety plans should be followed. The project may specify a dedicated rescue squad to increase safety. The contract documents should state the environmental limits such as flow conditions, daylight, and temperature that will control dives. The contractor’s approved plan should include goals of careful planning and organization to increase safety. For example, prior to heavy lifts, safety meetings should be held so everyone understands the lift procedure, the sequence of events, his personal responsibilities, and any back-up plans.

4-7. Tolerances

a. General. Setting of prefabricated elements may be complicated by underwater placements and by physical size and weight constraints. The use of spotting towers which extend from the element and above water is a common method which allows conventional survey and location methods. The use of self-centering guides such as cup-and-cone or similar stabbing guides are also common and highly recommended methods of locating elements precisely into final position while allowing reasonable set-in tolerances during positioning. Landing pads, smaller and more easily placed units, are typically used to allow more accurate positioning of large elements. Positioning of elements can also be monitored with electronic surveillance equipment. The Global Positioning System (GPS) along with sonar and related technologies have been utilized for position control in marine environments. Offsite prefabricated units are typically as large as practicable to take advantage of buoyancy and in order to minimize the number of structural connections required. Large units must generally be floated, rotated, translated, positioned, and interconnected; therefore, tolerances become far more important than for conventional construction. Diver verification of fit-up can be used, but this should be limited in scope and requires special attention to safety and scheduling issues. The appropriate selection of construction equipment, procedures, and templates can provide good tolerances without undue construction expense, complete reliance on divers, or delays. Appendix D contains information on representative tolerances that have been specified for projects utilizing prefabrication. The following discussion of tolerances is divided into topics related to prefabrication, installation, connections, site preparation, instrumentation, and operations.

b. Prefabrication tolerances. Tolerances must be considered during the fabrication of the units not only to ensure proper mating, but also for weight control. Weight control is an important aspect of prefabrication tolerances for units that are to be floated or lifted into place. Practical and obtainable tolerances are a function of such factors as the quality of the forms used, the use of match casting, and the survey/adjustment system used to address fabrication tolerances.

c. Installation tolerances. Installation tolerances on the order of 25 mm (1 inch) have been routinely achieved for prefabricated units up to 50,000 tonnes (55,100 tons); however, achieving these levels of tolerance requires careful planning and attention to engineering details. During installation, tolerances must be engineered to match both the environmental requirements along with the inherent accuracy of the positioning system. Environmental concerns include water plane stability, both global and local hydraulic forces, and possibly the use of station keeping systems. Station keeping and positioning systems include mooring-lines, spotter jacks, compensating lowering systems (such as the use of nitrogen gas over hydraulic fluid in rams for heave control), dolphins/spud piles, taut lines, prepositioned stabbing guides, and helper boats. Station keeping systems are frequently used together with feedback survey systems to improve positioning accuracy thus allowing tighter tolerances. In addition to dynamic feedback survey systems, the following sequence of survey considerations should be addressed when determining installation tolerances: (1) Survey of prefabricated units in the yard, which allows for correction and/or shimming of units before transport; (2) Underwater survey of the installation site, which allows for correction and/or adjustment of the landing/contact points prior to installation; and (3) Use of survey towers that extend above water, thus allowing the use of abovewater optical survey equipment together with instrumentation on the towers such as inclinometers and gyroscopes. Furthermore, when determining installation tolerances, it is important to consider the potential for adjusting the units after set-down by such means as: under-pressure to move the unit laterally or downward, underwater rams, and underwater lines.

d. Connection/interface tolerances. Connections/interfaces with foundations, existing-structures, previously placed units, floating structures, electrical systems, and mechanical units must be designed with sufficient simplicity, leeway, and/or adjustability to allow reasonable tolerances while ensuring full functionality. The use of underwater tremie concrete and grouts can greatly simplify the detailing of such connections. For connections to previously placed units, guides can be used such as a tapered pin and matching hole.

e. Tolerances associated with underwater site preparation. Obtaining and maintaining these tolerances against environmental disruptions are critical to the success of prefabricated construction. Consideration must be given to positioning of any piles and/or sheet piles, excavation/dredging tolerances, backfill tolerances, tolerances for drainage systems, screeding tolerances, and the potential use of inflatable mattresses and seals between shells that can relax the tolerances demanded. Furthermore, once the site has been prepared to the appropriate tolerance, it must be protected from such factors as scour, sedimentation, and debris by such means as temporary scour stone, protective mats, flow deflectors, and screens.

f. Tolerances associated with key operational elements or systems. Operability can be ensured not only by controlling tolerances, but also by preparing the construction plan appropriately. A thorough construction plan should include the following: (1) Avoiding joints at critical locations and/or relocating key elements so that they avoid crossing construction joints; (2) Allowing key apparatus (such as trunnions, secondary concrete placements, and machinery) to be installed in-the-dry without the use of a cofferdam; (3) Making reliable provisions for electrical wiring to pass across joints; (4) Allowing key elements to be referenced to each other; and (5) Allowing for secondary adjustment of elements after they have been positioned.

4-8. Acquisition Planning

a. Acquisition methods. Invitations for Bids (IFB) and Request for Proposals (RFP) are two basic forms of acquisition used for most procurements. IFB's are competitive procurements that do not allow the Government to evaluate the technical merits of the contractor's proposal and qualifications. An IFB procurement would not be a recommended acquisition method where a significant part of the contract documents is performance based. IFB's are more suited to contract documents that are entirely prescriptive, routine, or constructed by conventional techniques. For these reasons, an IFB would not be the recommended choice for a project involving innovative designs and construction concepts. Alternatively, RFP acquisitions will permit the Government to evaluate the technical merits of the contractor's proposal along with his qualifications and experience. An example of RFP procurement is a "best value" procurement, which provides a method to balance the technical merits of the contractor's proposal against the cost of performing the work. Best value is a two phase procurement process. In the first phase, the contractors submit their qualifications, experience, and a technical approach. The government evaluates and ranks the firms based on established evaluation criteria. The second phase of the procurement solicits final proposals, including cost, from the most highly ranked contractors. The contract is awarded to the contractor with the best value proposal, considering a combination of cost, technical merit, experience, schedule, risk, and other appropriate factors.

b. Acquisition team. A team should be formed to prepare the acquisition plan, develop the acquisition schedule, prepare the necessary acquisition documents, and evaluate proposals. Suitable time and funding needs to be built into the project schedule and budget for this team to evaluate proposals.

c. Acquisition schedule. A suitable schedule must be developed for the chosen method of acquisition for the project. The schedule must have sufficient time allotted for securing bids or proposals and for evaluations and subsequent negotiations with the selected contractor. Sufficient time must be allotted to conduct preproposal or prebid meetings, respond to inquiries from contractors, and issue addenda to the solicitation.

d. Development of price schedules. The development of the contract price schedule is an important consideration from the following points: (1) Project Acquisition, (2) Contract Administration, and (3) Development of a cost database for innovative construction techniques. The price schedule must break down the work into a number of bid items so the work is biddable, negotiable, and can be reasonably administered.

(1) Project acquisition. Prefabricated methods of construction could require rather unique bid items. The number of bid items and level of detail may provide a clear breakdown of the work, but must be weighed against the complexity and the additional work required to complete the cost proposal. A more detailed price schedule makes it easier to isolate a specific area of difference during negotiations. Some believe that more bid items result in higher bids, but this is not necessarily correct. A clear and thorough breakdown of the work will help prevent hidden costs, leave less questions as to what is to be included in "all inclusive" type payment items, and should help lessen the number of claims during execution of the contract. The Acquisition Team must permit ample time during the proposal phase for contractors to evaluate and complete the price schedule. The Acquisition Team must also coordinate the final schedule with the payment descriptions found in the contract specifications to ensure consistency and thoroughness of the payment statements. This must be done so that it is clear which costs will be included with which payment items. The price schedule may also be structured to conform to funding profiles, and may include optional work items and/or alternatives if the contractor is going to be permitted to bid alternates to the tender documents.

(2) Contract administration. The impacts and effect that the price schedule has in the administration of the contract must also be considered. The schedule must differentiate between items that can be administered as a job sum and those that will require measurement for payment. Distinct, well-defined features of work such as the prefabricated structure and the prefabrication yard may be paid for on a lump sum basis. Uncertain or variable work such as exploratory drilling, dredging, and some concrete items, where final quantities may vary from the theoretical quantities, must be paid for on a unit price basis. The price schedule should be structured so that all onsite work and all offsite work are identified separately.

(3) Cost databases. Since prefabricated methods of construction are new to most Districts, it will be important to begin the development of a cost database for innovative work. The price schedule should have separate items for each innovative construction item. This may create a more lengthy price schedule, but such a schedule will be beneficial for later procurements.

4-9. Division of Responsibility Between the Government and the Contractor

a. Design. For projects involving innovative designs and construction methods, contract specifications will probably be a mixture of performance-based and prescriptive requirements. Decisions must be made as to how much of the designs will be fully completed by the Government and which will be required of the contractor. This will also be true for construction procedures and sequences for the various features of work. Plans and specifications must be developed so that they are consistent with the selected method of acquisition. From a design perspective, it may be more clear-cut that most, if not all, of the critical structures should be completed by the Government, whereas minor structures or features may be presented more conceptually and left for the contractor to complete. There may ultimately be many possible ways to complete various features of the work; therefore, the contract documents should not be overly restrictive. Where the construction procedure must be prescriptive, the reasoning should be offered within the body of the specification for the contractor's understanding. The degree to which the contract plans and specifications are prescriptive or performance-based will directly affect bids and contingency costs in the contractor's bids. It is therefore essential that the project is reviewed by the design team and construction staff to identify areas where performance-based or prescriptive requirements are to be used.

b. Construction schedule and contract duration. The contract duration should be determined in consideration of probable flood events and associated delays. The onsite installation of float-in and lift-in construction will not be protected by a cofferdam and will be exposed to fluctuating water levels and various river velocities. Work will need to be scheduled and performed during specific periods when the weather/river/tides permit the work to be accomplished. The contract duration must consider periods of adverse weather, high water, and other natural occurrences that will affect project execution.

FOR THE COMMANDER:

HANS A. VAN WINKLE
Major General, USA
Deputy Commander for Civil Works

4 Appendices:
APP A - References
APP B - USACE Navigation Case Histories
APP C - Graphics and Photographs
APP D - Representation Project Planning Methodologies